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RECEIVER OPERATING CHARACTERISTIC TECHNIQUE FOR INDICATING CUT OFF VALUES OF LAKE TROPHIC STATE

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ABSTRACT

The research aimed at using a new technique (Receiver Operating Characteristic) to find cut off values for the transition between the adjacent trophic states for different parameters. Besides, a comparison among them is made according to their accuracy for the first time in environmental management of water resources. The data of 158 cases for 100 world lakes in the world were collected from the literature. The data included: chlorophyll a, Secchi depth transparency, total phosphorus, pH, total suspended solids, temperature and electrical conductivity for surface water; ammonia, NO_3/NO_2, hardness, alkalinity, silica and total phosphorus for water column, in addition to trophic state of the lake. Cut off values were found between the adjacent trophic status according to Receiver Operating Characteristic technique which include the area under the curve, sensitivity, specificity and accuracy. The results showed high sensitivity to indicate the trophic state approaching 98.5% with significance for chlorophyll a, total phosphorus, Secchi depth transparency for surface water and silica, total phosphorus and ammonia for total water column. The study concluded that Receiver Operating Characteristic had efficient ability to analyze trophic status of lakes and reservoirs.

KEYWORDS: Cut off Point, Eutrophication, Lakes, Reservoirs, ROC, Trophic State

Abbreviation

C.I.	Confidence Interval
ROC	Receiving Operating Characteristic
TP	Total Phosphorus
TSS	Total Suspended Solids
EC	Electrical Conductivity
NS	Not Significant

INTRODUCTION

Lakes and reservoirs exhibit changes in water quality due to water stagnancy or slow flowing. The nutrients concentrations increase and water becomes fertile (eutrophication) with the addition of nutrients from agricultural run off and human activities. The increase in fertility in lakes and reservoirs deteriorates water quality, rendering unpleasant tastes and odors, algal blooms and heavy growth of rooted aquatic plants. These features affect the use of water such as water supply, fisheries and recreations or aesthetic qualities. To define the degree of nutrients enrichment in lakes, the concept of trophic state is proposed. Trophic state is understood to be the biological response to forcing factors such as nutrients additions (Naumann, 1919; 1929).

Trophic state is based on the fact that changes in nutrients levels cause changes in algal biomass measured by chlorophyll a and changes in lake clarity measured by Secchi disk transparency. According to these parameters lakes could be classified into one of four trophic states: oligotrophic, mesotrophic, eutrophic, or hypereutrophic.

The frequently used biomass-related indices is that of Carlson (1977). The trophic state index (TSI) of Carlson used algal biomass as the basis for trophic state classification represented independently by three variables: chlorophyll pigments, Secchi disk transparency and total phosphorus. Unlike Nauman's typological classification of trophic state (Naumann, 1929), the index reflects a continuum of states. The range of the index is from approximately zero to 100. The state of the water body becomes worse with the increase of the index. This range was divided into categories. Each category represents a trophic state of water body.

Another studies developed a simplified model for trophic state of lakes (Organization for Economic Co-operation and Development (OECD), (1982)). Also, Salas and Martino (1991) developed a simplified trophic state model for the evaluation of eutrophication in warm water tropical lakes and reservoirs.

It is seen that these studies use more than single parameter and do not show the point of transition between adjacent stages and do not compare the indicating power among the variables.

Studies on the cutoff values for algal biomass variables among the states of eutrophication were not found in the literature. The opinion of cutoff values of water quality parameters between adjacent states of eutrophication may be more reliable than the categories of TSI. This research focuses on the cut off values among eutrophication stages.

The technique used successfully in different sciences to find cutoff values was receiver operating characteristic. Receiver operating characteristic (ROC) analysis had been used for radar signal detection in the War II. After that it was used to define cut off values for diagnostic tests in medicine and health care. Defining cut-off levels for diagnostic tests is a difficult process which should combine environmental and practical considerations with numerical evidence. It is wise to involve a statistician in studies of new diagnostic tests (Altman, 1991). Today the ROC analysis is a widespread method in the medical field and many textbooks and articles, for example (Bamber, 1975; Metz, 1978; DeLong et al., 1988; Hanley, 1989; McClish, 1989; Armitage & Berry; 1994) have descriptions of it.

This research tries to use ROC technique for the first time in environmental management of water resources to find cutoff values for different parameters of lake water quality and quantify their accuracy in indicating the trophic state of the lakes.

METHODS

The application of ROC technique needs data for large number of lakes at different trophic states. Therefore, the data for 158 cases for 100 lakes in the world were collected from the literature at the web site of International Lake Environment Committee (ILEC) (http://www.ilec.or.jp/database/). The data included: chlorophyll a, Secchi depth transparency, total phosphorus (TP), pH, total suspended solids (TSS), temperature and electrical conductivity (EC) for surface water; ammonia, NO_3/NO_2, hardness, alkalinity, silica and total phosphorus for water column, in addition to trophic status of the lake.

Receiver operating characteristic (ROC) analysis was conducted by drawing the relationships between sensitivity on y-axis versus 1-specificity on x-axis for different cut-off points within the range of the data for each parameter using SPSS 12 program. Sensitivity represents the number of true positive lakes (according to the indicated cutoff value) divided by total positive lakes (true and false), while specificity represent the true negative lakes divided by total negative lakes

(true and false) for a cut-off value (Figure 1). Area under the curve represents the power of the test to diagnose the trophic state of the lake for each parameter. The significance of this area for the selected parameter was found versus area of 0.5.

From the ROC curves, the cut off value which give the highest accuracy (the sum of true positive and true negative lakes divided by total number of lakes) represents the optimum one for mesotrophic versus oligotrophic, eutrophic versus mesotrophic and hypereutrophic versus eutrophic,.

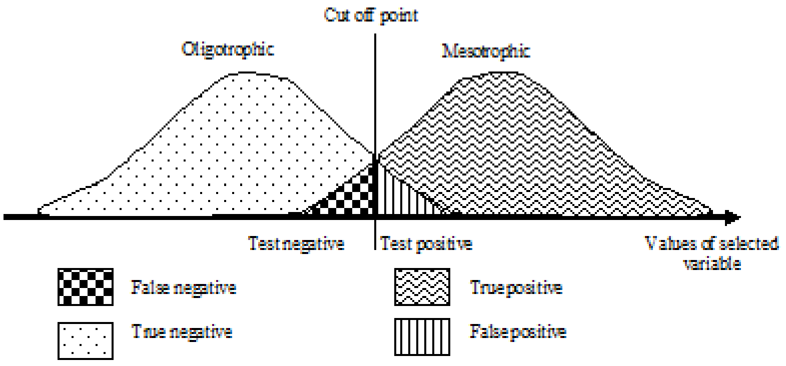
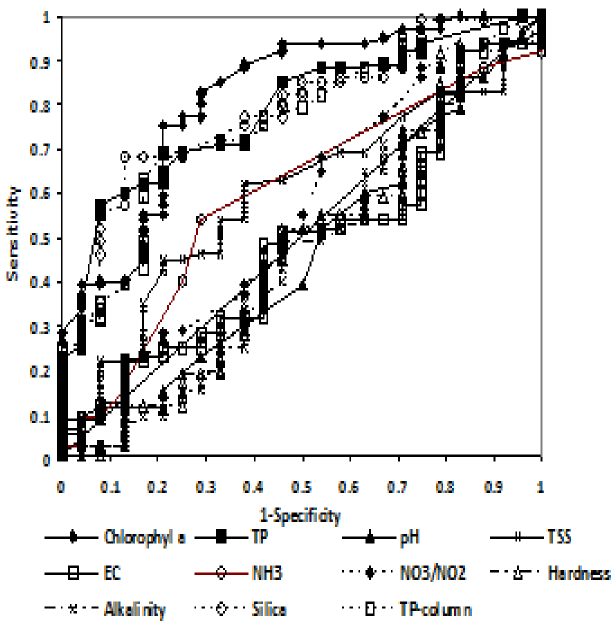


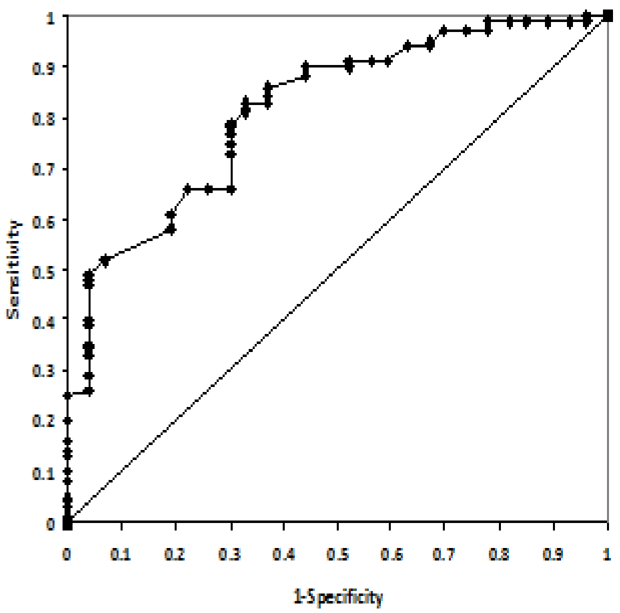
Figure 1: Sketch Explaining how Cut-Off Point of Selected Parameter Divide the Lakes into True Positive, True Negative, False Positive and False Negative for Mesotrophic Lakes versus Oligotrophic

RESULTS AND DISCUSSIONS

For ROC curves of mesotrophic lakes versus oligotrophic ones (Figure 2), the highest area under the curve was recorded for chlorophyll a and Secchi depth transparency with significance, then total phosphorus at surface, silica for water column and total phosphorus for total column (table 1). The cut off value was 1.65 µg/L for chlorophyll a and 4.1 m for Secchi. Silica had the highest sensitivity for indicating mesotrophic state (water column) with cut off value of 1.15 mg/L (table 2). Secchi cut off value was coincided with the classification of OECD (1982).



(a)



(b)

Figure 2: Receiver Operating Characteristic Curve for Indicating Mesotrophic Lakes Against Oligotrophic (a) for Different Parameters, (b) for Transparency

Table 1: ROC Area of the Measured Parameters for Indicating Mesotrophic Status of Lakes against Oligotrophic

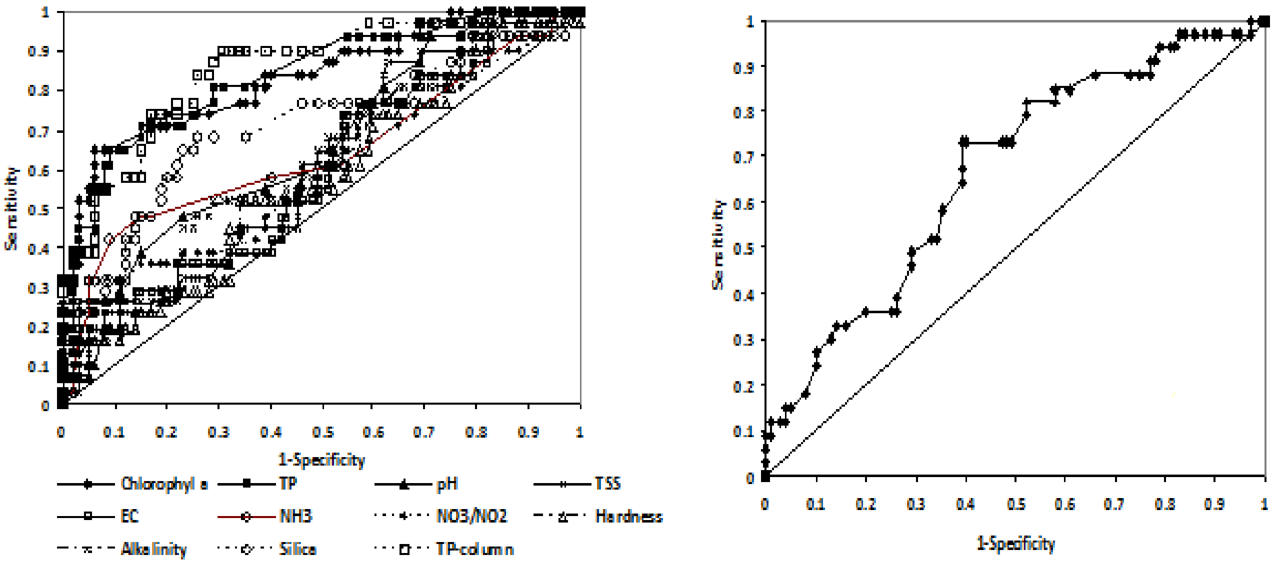
Parameters	Area	p-value	95% C.I.
Chlorophyll a	0.82	<0.001	0.72-0.92
TP	0.79	<0.001	0.69-0.89
Secchi depth transparency	0.82	<0.001	0.73-0.91
pH	0.46	0.56(NS)*	0.32-0.60
TSS	0.60	0.17(NS)	0.47-0.72
EC	0.49	0.82(NS)	0.35-0.62
Ammonia	0.59	0.19(NS)	0.46-0.72
NO_3/NO_2	0.55	0.50(NS)	0.41-0.69
Hardness	0.47	0.68(NS)	0.33-0.62
Alkalinity	0.46	0.59(NS)	0.32-0.61
Silica	0.79	<0.001	0.69-0.89
TP of the water column	0.75	<0.001	0.64-0.86

* NS = Not significant

Table 2: Optimum Cut-Off Value of Selected Parameters when Used to Diagnose Mesotrophic Lakes from Oligotrophic

Positive if Greater than or Equal to Cut Off Value	Sensitivity	Specificity	Accuracy
1.15 Silica (mg/L)	98.5	25.0	79.4
1.65 Chlorophyll a (μg/L)	94.0	54.2	83.7
7.5 TP (water column) (μg/L)	94.0	25.0	76.1
4.1 Secchi depth transparency (m)	89.6	55.6	80.8
8.9 TP (μg/L)	86.6	45.8	76.0

For ROC curves of eutrophic lakes versus mestrophic ones (Figure 3), the highest area under the curve was recorded for total phosphorus of the total column then total phosphorus of the surface and chlorophyll a with significant, in addition to silica, Secchi, pH, and ammonia (table 3). The cut off value for phosphorus of water column was 37.25 μg/L which lower than that recorded by OECD (1982) of 84.4 μg/L and 2.63 m for Secchi higher than that of OECD (1982) of 2.45 m (table 4). These parameters showed high specificity to indicate the mesotrophic lakes except for ammonia concentration which shows the highest sensitivity of 96.8% to indicate the eutrophic lakes with cut off value of 0.09 mg/L.



(a) (b)

Figure 3: Receiver Operating Characteristic Curve for Indicating Eutrophic Lakes Against Mesotrophic (a) for Different Parameters, (b) for Transparency

Table 3: ROC Area of the Measured Parameters for Indicating Eutrophic Lake against Mesotrophic

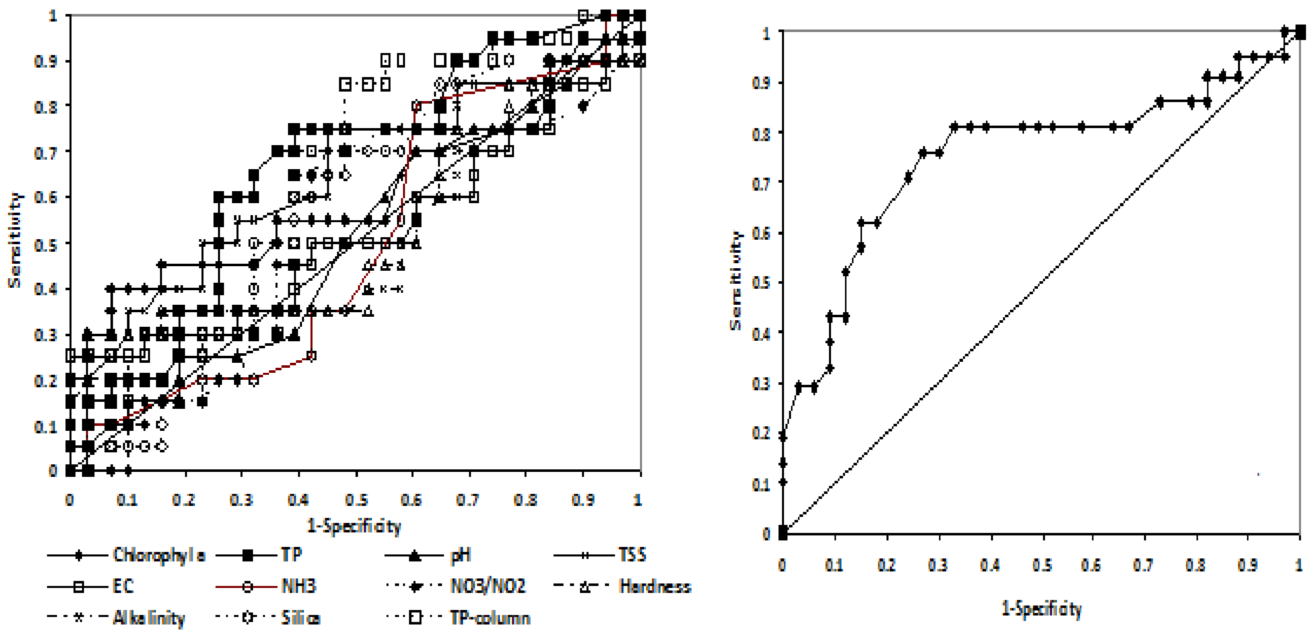
Parameters	Area	p-Value	95% C.I.
Chlorophyll a	0.837	<0.001	0.75-0.93
TP	0.840	<0.001	0.75-0.93
Secchi depth transparency	0.669	0.005	0.56-0.78
pH	0.651	0.017	0.54-0.77
TSS	0.603	0.104(NS)	0.49-0.72
EC	0.603	0.103(NS)	0.48-0.73
Ammonia	0.643	0.024	0.51-0.77
NO_3/NO_2	0.588	0.167(NS)	0.46-0.72
Hardness	0.579	0.210(NS)	0.46-0.70
Alkalinity	0.621	0.056(NS)	0.50-0.74
Silica	0.711	0.001	0.59-0.83
TP of the water column	0.856	<0.001	0.77-0.94

NS = Not significant

Table 4: Optimum Cut-Off Value of Selected Parameters when Used to Indicate Eutrophic Lakes from Mesotrophic

Positive if Greater than or Equal to Cut off Value	Sensitivity	Specificity	Accuracy
8.07 Chlorophyll a (µg/L)	64.5	92.3	84.0
28.75 TP (µg/L)	71.0	85.0	80.5
2.63 Secchi depth transparency (m)	72.7	61.0	64.5
8.65 pH	38.7	85.0	70.8
0.09 Ammonia (mg/L)	96.8	37.0	76.5
10.45 Silica (mg/L)	48.4	84.0	74.9
37.25 TP (water column) (µg/L)	74.2	83.0	80.4

For ROC curves of hypereutrophic versus eutrophic (Figure 4 and table 5), the highest area under the curve was for Secchi and then total phosphorus with significance. The cut off value for Secchi was 1.58 m with sensitivity of 76.2% and 73.0% for specificity (table 6).



(a) (b)

Figure 4: Receiver Operating Characteristic Curve for Indicating Hypereutrophic Lakes against Eutrophic (a) for Different Parameters, (b) for Transparency

Table 5: ROC Area of the Measured Parameters for Indicating Hypereutrophic Lake against Eutrophic

Parameters	Area	p-Value	95% C.I.
Chlorophyll a	0.61	0.20(NS)	0.44-0.78
TP	0.67	0.04	0.52-0.82
Transparency	0.75	<0.001	0.61-0.89
pH	0.50	0.99(NS)	0.34-0.67
TSS	0.64	0.08(NS)	0.48-0.81
EC	0.52	0.82(NS)	0.34-0.69
Ammonia	0.50	0.96(NS)	0.33-0.66
NO_3/NO_2	0.53	0.74(NS)	0.36-0.70
Hardness	0.53	0.73(NS)	0.36-0.70
Alkalinity	0.52	0.86(NS)	0.34-0.69
Silica	0.57	0.40(NS)	0.41-0.73
TP of the water column	0.64	0.11(NS)	0.48-0.79

Table 6: Optimum Cut-Off Value of Selected Parameters when Used to Indicate Hypereutrophic Lakes from Eutrophic

Positive if Greater than or Equal to Cut off Value	Sensitivity	Specificity	Accuracy
41.75 TP (μg/L)	75.0	61.0	66.6
1.58 Secchi depth transparency (m)	76.2	73.0	74.1

CONCLUSIONS

- Chlorophyll a levels have the highest power to indicate the progression of trophic state from oligotrophic to mesotrophic and from oligotrophic to eutrophic with cut off values of 1.65 and 3.05 μg/L respectively.
- Total phosphorus for water column is a good indicator of trophic state progression with a sensitivity of 94.0% for oligtrophic to mesotrophic lake at cut off value of 7.5 μg/L.
- Secchi depth transparency exhibits significant results diagnosing lakes trophic status with cut off values 4.1, 2.63 and 1.58 m for mesotrophic, eutrophic and hypereutrophic respectively.
- Receiver operating characteristics technique is a good tool to indicate cut off values and compare the accuracy for different parameters and more specific studies on lakes.

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